2P1-4

Acoustic low-frequency forbidden transmission in solid-fluid superlattices

固体流体超格子における音響低周波禁制透過

Seiji Mizuno[1] (Grad. School of Eng., Hokkaido Univ.)
水野誠司 (北大工)

1. Introduction

During the last three decades, a lot of studies have been devoted to acoustic waves or phonons in phononic crystals [1]. The noticeable features of phonons in these structures are fundamentally related to the existence of the phononic bandgaps due to the Bragg reflections of phonons, which are determined by the artificially designed period.

In addition to this Bragg bandgap, there exists other type of gap, which originates from a local resonant mechanism. This mechanism can lead to the formation of lower frequency phononic bandgaps, which are useful for various devices, such as low frequency acoustic filters and subwavelength one-way diodes.

One of the simplest structure giving the non-Bragg phononic bandgaps is a one-dimensional solid-fluid superlattice consisting of alternating elastic solid and fluid layers. In a previous paper, we examined the origin of the non-Bragg phononic bandgap [2]. Very recently, Sai Zhang et al. [3] studied the acoustic low-frequency forbidden transmission (LFT) in solid-fluid superlattices. In particular, they examined the angle range in which the LFT occurs, because the LFT exists only for a small incident angle range. They also demonstrated the angle-range variation characteristics of the LFT using the control variable method. However, the mechanism of the LFT still remains unclear.

In the present study, we discuss the frequency range in which the acoustic LFT can be seen.

2. Method of Calculation

We assume that the solid and fluid layers are isotropic continuum and ideal fluids, respectively. In the solid layer, the phonon modes polarized in the sagittal plane and the horizontally polarized shear mode are decoupled. We consider the sagittal modes. Then, viscous shear stresses vanish in the fluid layers and at the interfaces between solid and fluid layers.

The other boundary conditions are that the normal stress and normal velocity are continuous at the interfaces between the solid and fluid layers.

These boundary conditions are expressed in terms of the transfer matrix. Using the transfer matrix method, we numerically calculate phononic bandstructure and transmission spectrum of solid-fluid superlattices.

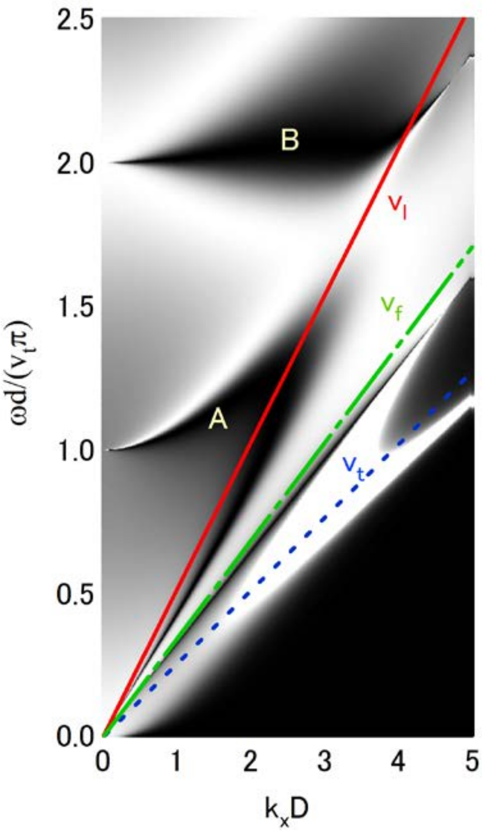

Fig. 1 Transmittance of phonons propagating through a PVC/water superlattice in fluid. The number of period is assumed to be 1. The red (solid) and blue lines (dots) illustrate the longitudinal and transverse velocities in PVC, and the green line is the longitudinal velocity in water.

[1]e-mail address: mizuno@eng.hokudai.ac.jp

3. Numerical results and discussions

As the first example, we show in Fig. 1 the phonon transmittance for a water/PVC superlattice as a function of $k_x = \omega / v_f \sin\theta$, which is the wave vector component parallel to the interfaces. The number of period is assumed to be 1. In this figure, the red, blue, and green lines are the longitudinal and transverse velocities in PVC, and the longitudinal velocity in water, respectively.

In this calculation, parameters we used are as follows: ρ = 1.20 g/cm³, v_t = 1.38 km/s, and v_ℓ = 2.70 km/s for Plexiglas; ρ = 1.00 g/cm³, v_ℓ = 1.49 km/s for water. The thickness of the solid layer is denoted by d.

Even though the number of periods is assumed to be 1, there exist forbidden transmission ranges (indicated by A and B in Fig. 1), which correspond to resonance gaps suggested in Ref. [2]. Below the red line representing $\omega = v_\ell k_x$, we can see the gaps. Here, we note that the longitudinal wave becomes evanescent in the fluid regions below the green line representing $\omega = v_f k_x$. Thus, we are not interested in this frequency range.

Figure 2 is the transmittance calculated for N = 8. The thickness of a fluid layer is assumed to be the same as the thickness d of a solid layer. In addition to the resonance gaps, we can see the clear Bragg gap indicated by C, which originate from the Bragg reflection of phonons scattered by the multilayer structure. Due to the effect of the multiple reflection, resonance gaps are clearly seen, compared with the results for N = 1.

Here, we focus on the resonance gap lower than the Bragg gap. The gap A shown in Fig. 1 is divided into two regions A_1 and A_2 in Fig.2. The region A_1 is in contact with the region A_2 at a point, which corresponds to a flat band. At this point, the frequency band have no dispersion as a function of k_z, the wave vector component perpendicular

The red line intersects the resonance gap (A). Below this red line, the longitudinal component of the phonon becomes evanescent. However, transverse component has a form of propagating wave above the blue line. As a result, phonons can go through the superlattice, and high transmission and forbidden transmission rages can coexist.

4. Concluding remarks

We theoretically examined the phonon transmission through a solid/fluid superlattice. In particular, we focused on the frequency ranges lower than the Bragg gaps. In addition to the results shown in the present proceedings, we will discuss the transmission properties of phonons within the frequency range below the red line, based on the analytical expressions for the transmittance.

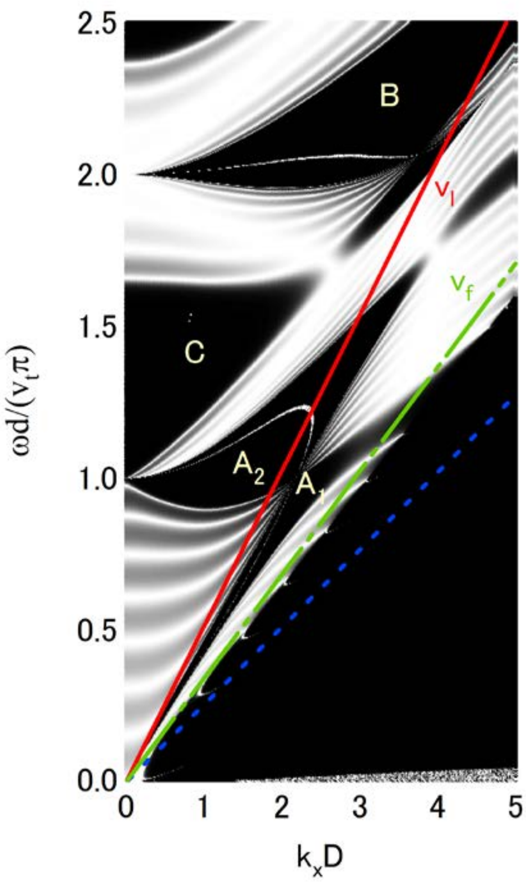

Fig. 2 Transmittance of phonons propagating through a PVC/water superlattice in fluid. The number of period is assumed to be 8, and the period is $D = 2d$.

References

1. S. Mizuno: *Horizons in World Physics,* NOVA, New York, 2017) Chapter 2.
2. S. Mizuno: Jpn. J. Appl. Phys. **55** (2016) 017302.
3. Sai Zhang, Bai-qiang Xu, and Wenwu Cao: J. Appl. Phys. **123** (2018) 115111.